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2013 Review on the Extension of the *AMedP-8(C)* Methodology to New Agents, Materials, and Conditions

Lucas A. LaViolet
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June 2014

IDA Document D-4802
Log: H 14-000697

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About This Publication

The work was conducted by the Institute for Defense Analyses (IDA) under contract DASW01-04-C-0003, Task CA-6-3079, "CBRN Casualty Estimation Work Effort of the Medical CBRN Defense Planning & Response Project," for the Joint Staff, Joint Requirements Office for CBRN Defense and the U.S. Army Office of the Surgeon General. The views, opinions, and findings should not be construed as representing the official position of either the Department of Defense or the sponsoring organization.

Acknowledgments

The authors would like to thank Ms. Julia K. Burr, Dr. Audrey C. Kelley, Dr. Sean M. Oxford, and Dr. Katherine M. Sixt for assistance in rating the estimated impact and level of effort for each of the proposed enhancements discussed in this document. The authors are also grateful to Mr. Douglas P. Schultz for reviewing, Dr. Elisse W. Barnes for editing, and Ms. Barbara Varvaglione for producing this document.

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Executive Summary

In 2009, the Institute for Defense Analyses (IDA) produced the final draft of a North Atlantic Treaty Organization (NATO) guide documenting a methodology to estimate casualties from chemical, biological, radiological, and nuclear (CBRN) weapons. That document, *Allied Medical Publication 8 (C): NATO Planning Guide for the Estimation of CBRN Casualties,* (*AMedP-8(C)*), officially promulgated in March 2011, included the parameters to estimate casualties caused by three chemical agents, five biological agents, seven radioisotopes, nuclear fallout, and prompt nuclear effects. Each year since 2009, IDA has published an annual review that extends this methodology to new agents, materials, and conditions.

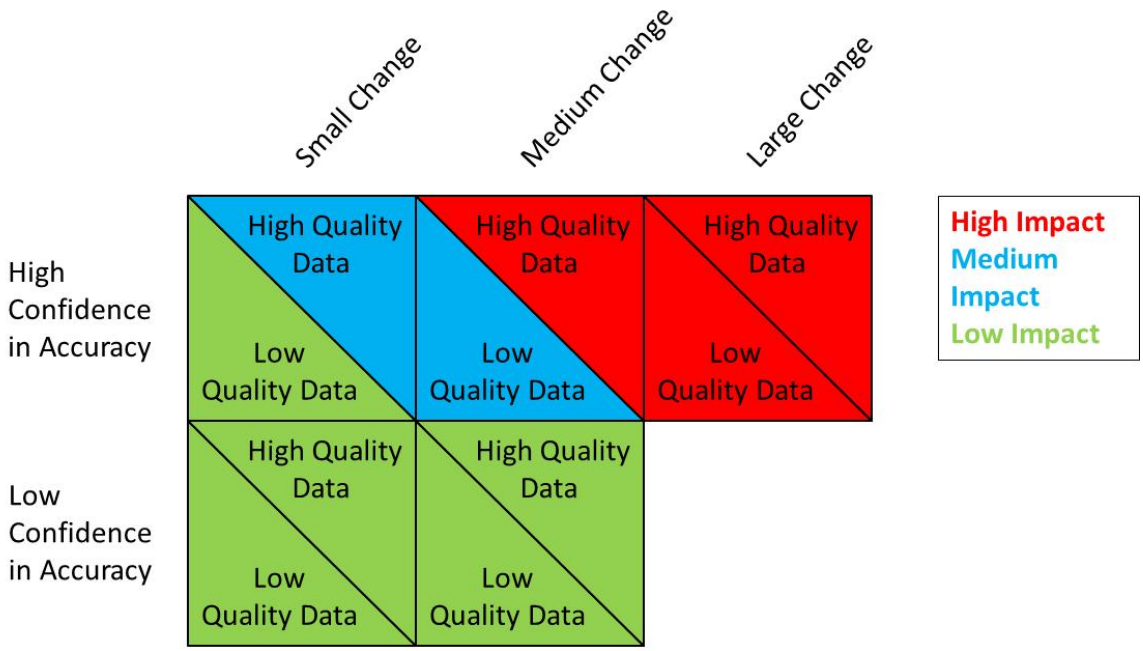
As IDA has implemented recommendations from these annual reviews, the scope of the *AMedP-8(C)* methodology has expanded, and further enhancements are expected as new information is identified each year. The objective of this document, the 2013 review, is to provide a framework to assess the relative costs and benefits of modifications to the *AMedP-8(C)* methodology to inform the prioritization of future efforts.

To identify potential enhancements to the *AMedP-8(C)* methodology for the 2013 review, the IDA research team reviewed the recommendations of the four prior annual reviews. Additional topics were identified during the course of recent studies and analyses by the IDA team and through a review of the assumptions and limitations of *AMedP-8(C)*. In total, this process yielded 14 potential enhancements.

After identifying a number of improvements to the *AMedP-8(C)* methodology, the IDA team heuristically assessed their implications by ranking their impact and the level of effort required to implement them on an ordinal three-point scale (high, medium, or low). The purpose of the two ratings is to frame the costs and benefits of implementing various potential enhancements in a way that allows the sponsors to compare alternatives and select a strategy for prioritizing future enhancements to the methodology.

For these assessments, level of effort was defined as a proxy for the time and monetary costs associated with the research and implementation of the proposed enhancement by the IDA team. In general, higher effort enhancements to the methodology will require more time and manpower to carry out than lower effort enhancements. Impact was defined as the effect of the proposed enhancement on the methodology's utility to its users. The change in utility of the methodology to these users is a function of the magnitude of (1) the difference between casualty estimates with and

without the proposed enhancement, (2) the IDA team's confidence that the enhancement would increase the accuracy of the casualty estimate given high quality data, and (3) the quality of the data availability to model the enhancement. This is represented visually in the following figure in which the final impact rating (high, medium, or low) is indicated by color (red, blue, or green, respectively). As an example, the blue triangle in the middle column signifies that an enhancement to the methodology that is estimated to result in a medium change in the magnitude of the casualty estimate, for which the IDA team has high confidence that the accuracy of the casualty estimate would be improved given high quality data, and for which there is estimated to be low quality data, would be a medium impact enhancement.



Note: Small vs. medium vs. large change = the estimated magnitude of change in the casualty estimate; high vs. low confidence in accuracy = the IDA team's confidence that the enhancement will increase the accuracy of the casualty estimate given high quality data; high vs. low quality data = the estimated quality of the data available to model the enhancement.

Estimated Impact of a Potential Enhancement to the *AMedP-8(C)* Casualty Estimation Methodology

The following table summarizes the estimated ratings for both the impact (as well as its contributing factors) and level of effort for each of the potential enhancements to the *AMedP-8(C)* methodology. Justifications for these assessments are discussed in Chapter 2. It is important to note that the ratings of impact and effort provided in this document are only estimates; the actual values, once the analyses are initiated or the enhancements implemented, may be either higher or lower than the qualitative values provided.

Estimated Impact and Level of Effort Ratings for Potential Enhancements to the *AMedP-8(C)* Methodology

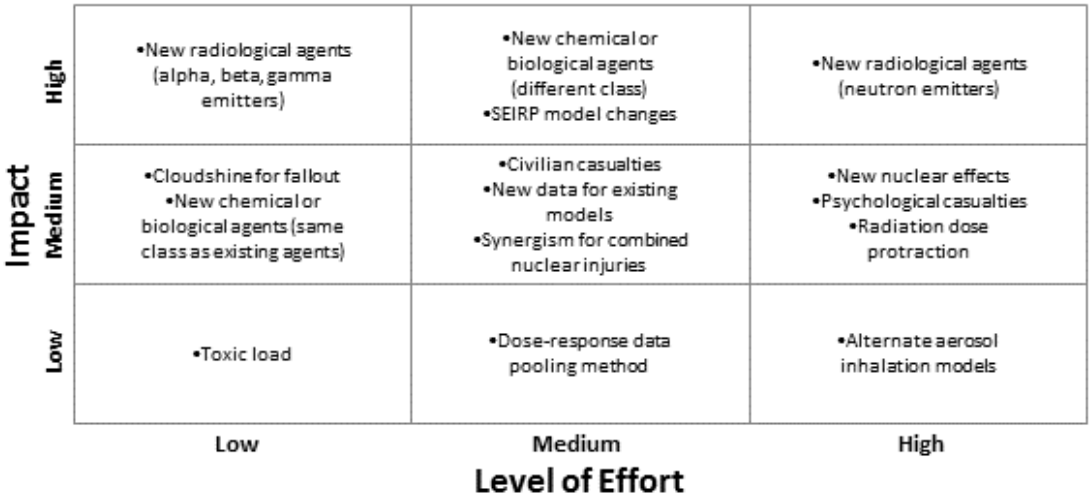
Enhancement	Magnitude of Change[a]	Confidence in Accuracy[b]	Quality of Data[c]	Impact	Level of Effort
Dose-response data pooling method	Small	Low	High	Low	Medium
Alternate aerosol inhalation models	Medium	Low	Low	Low	High
Civilian casualties	Medium	High	Low	Medium	Medium
Psychological casualties	Medium	High	Low	Medium	High
New data for existing models	Small	High	High	Medium	Medium
New chemical or biological agents (same class as existing agents)	Small	High	High	Medium	Low
New chemical or biological agents (different class)	Large	High	Low/High	High	Medium
Toxic load	Medium	Low	High	Low	Low
SEIRP model changes	Medium	High	High	High	Medium
New radiological agents	Large	High	High	High	Low/High
Radiation dose protraction	Medium	High	Low	Medium	High
Cloudshine for fallout	Small	High	High	Medium	Low
New nuclear effects	Medium	High	Low	Medium	High
Synergism for combined nuclear injuries	Medium	High	Low	Medium	Medium

[a] Estimated magnitude of change in casualty estimate (arbitrary scale) (Small, Medium, Large)

[b] Confidence that enhancement will increase accuracy of casualty estimate given high quality data (Low, High)

[c] Quality of data available to model enhancement (Low, High)

The following figure shows these enhancements plotted on a matrix of estimated impact versus level of effort, which not only allows decision makers to visually compare the options, but also provides a framework by which to prioritize them. Four prioritization schemes based on this matrix are described as well.



Potential Enhancements to the *AMedP-8(C)* Methodology Plotted on a Matrix of Estimated Impact versus Level of Effort

The first of the four systems that could be used to prioritize future efforts to extend the *AMedP-8(C)* methodology, Prioritization Scheme 1 (Highest Impact), gives precedence to the higher impact enhancements, with the secondary metric being a lower level of effort. An alternate method of ranking options, Prioritization Scheme 2 (Lowest Effort), reverses the two preferences from the first system, first prioritizing those that require the least amount of effort and then choosing the highest impact options from among those of equal effort. Another option would be to first prioritize those enhancements that provide a high impact relative to the level of effort estimated to implement them (designated "high value"). For instance, a medium impact/low level of effort modification would be a higher priority than a high impact/high effort enhancement. Prioritization Scheme 3 (High Value, High Impact) and Prioritization Scheme 4 (High Value, Low Effort) are both variations of this approach. The former gives preference to those with higher impact, while the latter gives preference to those with a lower level of effort. In each of the four prioritization schemes described, sponsor preference or user demands would determine the order of potential enhancements contained within the same cell of the matrix.

Each of the four prioritization schemes results in a different rank-order of the 14 potential enhancements to the *AMedP-8(C)* methodology. These rankings are shown in the following figure, which allows for an easy comparison of the four alternatives. Each column represents one of the four prioritization schemes, with the highest priority enhancement according to that ranking system at the top of the column. Since the four schemes all prioritize higher over lower impact enhancements and lower over higher effort enhancements, there are some trends among the results. For instance, the highest priority enhancement according to all four schemes is adding certain new radiological

agents, because it was rated a high impact, low effort enhancement. Likewise, the low impact, high effort task of conducting comparative analyses of alternate aerosol inhalation models was consistently rated the lowest priority enhancement across the schemes.

Priority	Prioritization Scheme 1: Highest Impact	Prioritization Scheme 2: Lowest Effort	Prioritization Scheme 3: High Value, High Impact	Prioritization Scheme 4: High Value, Low Effort
High	•New radiological agents (alpha, beta, gamma emitters)	•New radiological agents (alpha, beta, gamma emitters)	•New radiological agents (alpha, beta, gamma emitters)	•New radiological agents (alpha, beta, gamma emitters)
	•New chemical or biological agents (different class) •SEIRP model changes	•Cloudshine for fallout •New chemical or biological agents (same class as existing agents)	•New chemical or biological agents (different class) •SEIRP model changes	•Cloudshine for fallout •New chemical or biological agents (same class as existing agents)
	•New radiological agents (neutron emitters)	•Toxic load	•Cloudshine for fallout •New chemical or biological agents (same class as existing agents)	•New chemical or biological agents (different class) •SEIRP model changes
	•Cloudshine for fallout •New chemical or biological agents (same class as existing agents)	•New chemical or biological agents (different class) •SEIRP model changes	•New radiological agents (neutron emitters)	•Toxic load
	•Civilian casualties •New data for existing models •Synergism for combined nuclear injuries	•Civilian casualties •New data for existing models •Synergism for combined nuclear injuries	•Civilian casualties •New data for existing models •Synergism for combined nuclear injuries	•Civilian casualties •New data for existing models •Synergism for combined nuclear injuries
	•New nuclear effects •Psychological casualties •Radiation dose protraction	•Dose-response data pooling method	•Toxic load	•New radiological agents (neutron emitters)
	•Toxic load	•New radiological agents (neutron emitters)	•New nuclear effects •Psychological casualties •Radiation dose protraction	•Dose-response data pooling method
	•Dose-response data pooling method	•New nuclear effects •Psychological casualties •Radiation dose protraction	•Dose-response data pooling method	•New nuclear effects •Psychological casualties •Radiation dose protraction
Low	•Alternate aerosol inhalation models	•Alternate aerosol inhalation models	•Alternate aerosol inhalation models	•Alternate aerosol inhalation models

Prioritized Rankings of Potential Enhancements to the *AMedP-8(C)* Methodology Resulting from the Application of the Four Prioritization Schemes

The specific ordering of the potential enhancements shown in the figure above is not as important as the framework for developing the prioritized lists. The process is

qualitative, but transparent and easily adaptable. IDA (or the sponsors) could easily change these ratings if new information becomes available for any of the possible modifications described in Chapter 2 or if the sponsors disagree with the qualitative assessments of impact or level of effort. An added benefit of this framework is the ease of adding another potential enhancement to the prioritized list. When a new enhancement to the methodology is identified, its impact and effort must simply be rated on the same three-point scale used for the enhancements described in this document to determine its placement on the matrix.

The IDA team recommends utilizing one of the four prioritization schemes to rank future enhancements to the *AMedP-8(C)* methodology: (1) Highest Impact, (2) Lowest Effort, (3) High Value, High Impact, or (4) High Value, Low Effort. However, the choice of which scheme to apply to the matrix depends on the sponsors' preferences and available resources. The exercise of using the prioritization schemes imposes deliberate consideration of the various alternatives for investing in future enhancements to the *AMedP-8(C)* methodology and helps inform the sponsors' decisions regarding how to allocate resources.

Contents

1. Introduction

A. Objective

In 2009, the Institute for Defense Analyses (IDA) produced the final draft of a North Atlantic Treaty Organization (NATO) guide documenting a methodology to estimate casualties from chemical, biological, radiological, and nuclear (CBRN) weapons. That document, *Allied Medical Publication 8 (C): NATO Planning Guide for the Estimation of CBRN Casualties,* (*AMedP-8(C)*), officially promulgated in March 2011, included the parameters to estimate casualties caused by three chemical agents, five biological agents, seven radioisotopes, nuclear fallout, and prompt nuclear effects. Each year since 2009, IDA has published an annual review that extends this methodology to new agents, materials, and conditions.

As IDA has implemented recommendations from these annual reviews, the scope of the *AMedP-8(C)* methodology has expanded, and further enhancements are expected as new information is identified each year. The objective of this document, the 2013 review, is to provide a framework to assess the relative costs and benefits of potential modifications to the *AMedP-8(C)* methodology to inform the prioritization of future efforts.

This review is structured into three chapters. This introductory chapter states the objective of the 2013 annual review as well as the task requirements it fulfills. It also briefly introduces the *AMedP-8(C)* casualty estimation methodology and summarizes the past annual reviews and subsequent programs of work completed by IDA. Chapter 2 describes the impact of each enhancement identified, as well as the level of effort required to modify the methodology. Finally, Chapter 3 ranks the potential enhancements and describes four possible schemes for prioritizing future work based on the relative impact versus effort ratings from the previous chapter.

B. Task Requirements

This document describes research IDA has performed for the Joint Staff, Joint Requirements Office (JRO) for CBRN Defense, (J-8/JRO) and the United States (U.S.) Army Office of the Surgeon General (OTSG) under Task Order CA-6-3079 "CBRN Casualty Estimation Update of the Medical CBRN Defense Planning and Response Project," Subtask 2 "Update Agents/Materials into *AMedP-8(C)* Methodology." The order specifically directs IDA to provide a "draft program of work identifying agents, effects, materials, and conditions of interest to the Department of Defense (DOD) (and

NATO and other Federal agencies, as requested), but not currently included in *AMedP-8(C).*"

C. Background

AMedP-8(C) describes a general methodology military planners can use to estimate casualties from CBRN weapons. In its annexes, *AMedP-8(C)* defines specific modeling parameters for three chemical agents (sarin [GB], methylphosphonothioic acid nerve agent (VX), and distilled mustard [HD]), five biological agents (those that cause anthrax, botulism, pneumonic plague, smallpox, and Venezuelan equine encephalitis [VEE]), seven radioisotopes (^{60}Co, ^{90}Sr, ^{131}I, ^{137}Cs, ^{192}Ir, ^{238}Pu, and ^{241}Am), and acute nuclear blast, radiation, and thermal effects.

The *AMedP-8(C)* methodology depends on national hazard prediction models for its inputs. These models must provide the amount of CBRN agent or effect present over time at *icons* (groups of co-located individuals) in the scenario. The *AMedP-8(C)* methodology then characterizes human responses to exposure as a stepwise function of injury severity over time (called an injury profile). Based on the available data for chemical, radiological, and nuclear agents and effects, clinically distinguishable dose/dosage/insult ranges are developed for each agent or effect, and injury profiles are drawn for all ranges. Individuals are considered casualties at the time the injury profile first reaches a user-defined injury severity level.

For biological agents, the following five submodels are combined to determine the number of casualties over time.

1. The infectivity submodel estimates the number of individuals that become ill as a function of inhaled dose of agent.
2. The incubation period submodel estimates the time from exposure to the onset of symptoms.
3. The duration of illness submodel estimates the time from onset of symptoms to either death or recovery.
4. The disease profile submodel divides the illness into clinically differentiable stages and assigns each an injury severity level.
5. The lethality submodel estimates the number of individuals that die.

Just like for the chemical, radiological, and nuclear methodologies, individuals are considered casualties when the symptoms from a biological agent exposure (as defined by the disease profile submodel) reach a user-defined threshold.

D. Past Reviews and Subsequent Program of Work

In 2009, the same year IDA published the final draft of *AMedP-8(C)*, the sponsors tasked IDA to nominate new agents to be considered for future versions of *AMedP-8*. The resulting analysis identified nearly 900 chemical and biological materials of concern to various governmental agencies. IDA further reviewed a representative subset of agents for the availability of human response modeling data. Based on this review, IDA estimated the level of effort required to extend the *AMedP-8(C)* methodology to include these new agents. This analysis, along with estimates of the level of effort to include psychological or civilian casualties, made up the *2009 Report on the Extension of the AMedP-8(C) Methodology to New Agents, Materials, and Conditions.*[1] This became the first in a series of annual reviews intended to update and expand the *AMedP-8(C)* methodology.

The following year, IDA published the ratification draft of *AMedP-8(C)*[2] as well as its technical reference manual[3] documenting the derivation of the underlying parameters. In addition, IDA developed human response parameters for five additional biological agents: Staphylococcal enterotoxin B (SEB) and the causative agents of brucellosis, glanders, Q fever, and tularemia.[4] The second annual review[5] recommended extending the *AMedP-8(C)* methodology to include the impact of medical care and adding new agents to *AMedP-8(C)* to better align with the Common User Database (CUD), a U.S. tool that estimates the medical requirements for different types of patients. Since the outputs of the *AMedP-8(C)* methodology are roughly equivalent to the inputs to the CUD, including the same CBRN agents and effects in both methodologies would benefit

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1 Carl A. Curling, Lucas A. LaViolet, and Julia K. Burr, *2009 Report on the Extension of the AMedP-8(C) Methodology to New Agents, Materials, and Conditions*, IDA Document D-3945 (Alexandria, VA: Institute for Defense Analyses, October 2009).

2 North Atlantic Treaty Organization (NATO), "AMedP-8(C): NATO Planning Guide for the Estimation of Chemical, Biological, Radiological, and Nuclear (CBRN) Casualties," STANAG 2553 (Brussels: NATO, March 2011).

3 Carl A. Curling et al., *Technical Reference Manual: Allied Medical Publication 8(C), NATO Planning Guide for the Estimation of Chemical, Biological, Radiological, and Nuclear (CBRN) Casualties*, IDA Document D-4082 (Alexandria, VA: Institute for Defense Analyses, August 2010).

4 Carl A. Curling et al., *Parameters for the Estimation of Casualties from Exposure to Specified Biological Agents: Brucellosis, Glanders, Q Fever, SEB and Tularemia*, D-4132 (Alexandria, VA: Institute for Defense Analyses, November 2010); and Carl A. Curling et al., *Addenda to Allied Medical Publication 8, "NATO Planning Guide for the Estimation of Chemical, Biological, Radiological, and Nuclear (CBRN) Casualties" (AMedP-8(C))–Parameters for Estimation of Casualties from Exposure to Specified Biological Agents*, IDA Document D-4133 (Alexandria, VA: Institute for Defense Analyses, January 2011).

5 Carl A. Curling, Lucas A. LaViolet, and Julia K. Burr, *2010 Review on the Extension of the AMedP-8(C) Methodology to New Agents, Materials, and Conditions*, IDA Document D-4131 (Alexandria, VA: Institute for Defense Analyses, December 2010).

planners. As the status of the CUD has recently changed, plans for this alignment have been postponed until the future of the CUD is more certain.

The 2011 program of work included modeling medical intervention for all CBRN agents and effects in *AMedP-8(C)* as well as for the five additional biological agents modeled in 2010.[6] The third annual review[7] prioritized an analysis of the effect of bioscavengers on chemical nerve agents, the inclusion of historical data from experiments with military research volunteers (MRV) from the U.S. offensive weapons program, and the expansion of the methodology to include a number of additional agents of interest to the sponsors.

In 2012, IDA began to develop human response modeling parameters for five new chemical agents (chlorine, cyanogen chloride, hydrogen cyanide, hydrogen sulfide, and phosgene) and seven new biological agents (ricin, T-2 mycotoxin, and the causative agents of eastern equine encephalitis [EEE], Ebola, Marburg, melioidosis, and western equine encephalitis [WEE]). In addition, IDA investigated the potential use of bioscavengers to treat chemical injuries and sought access to the set of MRV exposure data for Q fever, SEB, and tularemia. The 2012 review[8] examined literature published since 2009 and proposed three broad recommendations: (1) develop an updated version of *AMedP-8(C)* that incorporates previously completed additions to the methodology and editorial changes to keep medical countermeasure content current, (2) conduct analyses to determine the benefits of adding newly identified data into the *AMedP-8(C)* methodology, and (3) compare *AMedP-8(C)* models to other published models for validation or revision.

IDA's focus in 2013 was on developing the initial draft of *AMedP-7.5(A)*.[9] This document, the successor to *AMedP-8(C)*, proposes human response parameters for

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6 Carl A. Curling et al., *The Impact of Medical Care on Casualty Estimates from Battlefield Exposure to Chemical, Biological and Radiological Agents and Nuclear Weapon Effects,* IDA Document D-4465 (Alexandria, VA: Institute for Defense Analyses, March 2012); and Carl A. Curling et al., *Addenda to Allied Medical Publication 8, "NATO Planning Guide for the Estimation of Chemical, Biological, Radiological, and Nuclear (CBRN) Casualties (AMedP-8(C)) to Consider the Impact of Medical Treatment on Casualty Estimation*, IDA Document D-4466 (Alexandria, VA: Institute for Defense Analyses, December 2012).

7 Carl A. Curling, Lucas A. LaViolet, and Julia K. Burr, *2011 Review on the Extension of the AMedP-8(C) Methodology to New Agents, Materials, and Conditions*, IDA Document D-4486 (Alexandria, VA: Institute for Defense Analyses, December 2011).

8 Lucas A. LaViolet, Julia K. Burr, and Carl A. Curling, *2012 Review on the Extension of the AMedP-8(C) Methodology to New Agents, Materials, and Conditions*, IDA Document D-4727 (Alexandria, VA: Institute for Defense Analyses, October 2013).

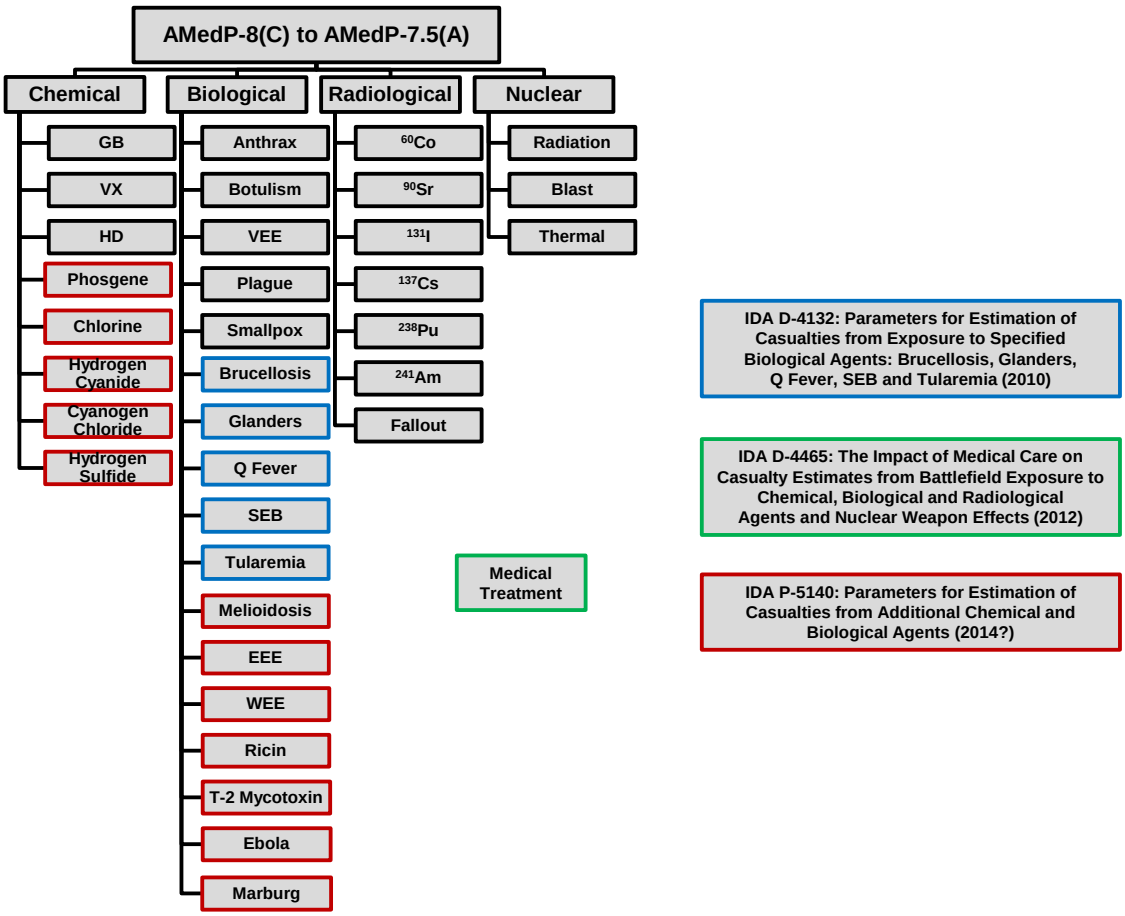
9 As part of an ongoing Standardization Agreement (STANAG) review and consolidation, the NATO Standardization Board has renumbered all existing CBRN-related Allied Medical Publications as *AMedP-7.x*. Thus all future versions of *AMedP-8* will be designated *AMedP-7.5(x)*. In this publication,

additional agents and incorporates the effects of medical care within the casualty estimation methodology. In addition, IDA finalized the modeling parameters for the 12 new agents initiated in 2012 and reviewed the potential use of radioprotectant drugs and radiation injury treatments to change the casualty estimate and require revisions to existing policy, doctrine, and technical documentation.

Figure 1 summarizes the evolution of the CBRN casualty estimation methodology over time. The boxes outlined in black represent CBRN agents or effects that are included in *AMedP-8(C)*. Subsequently modeled agents and medical treatment, which are proposed for inclusion in *AMedP-7.5(A)*, are represented by boxes outlined in the color of the box around corresponding IDA publications that document those enhancements to the methodology.[10]

references to the currently ratified document will retain the *AMedP-8(C)* designation, while references to the next version will have the *AMedP-7.5(A)* designation.

[10] Oxford, Sean M. et al, *Parameters for Estimation of Casualties from Additional Chemical and Biological Agents*, IDA Paper P-5140, is currently in draft and will likely be published in 2014.



Note: Agents and effects published in *AMedP-8(C)* are outlined in black; subsequent enhancements to the methodology proposed for inclusion in *AMedP-7.5(A)* are outlined in blue, red, and green.

Figure 1. Evolution of the CBRN Casualty Estimation Methodology

2. The 2013 Review

A. Approach

The purpose of the 2013 review was to develop a prioritization scheme for future enhancements to the *AMedP-8(C)* methodology. First, the IDA research team identified potential modifications to the methodology from past publications and analyses. Second, the team rated the impact of each possible enhancement and the level of effort required to implement the enhancement. Finally, it presents approaches to prioritize future work based on the positions of the proposed enhancements on a matrix of impact versus effort. The remainder of this chapter will describe the first two steps of this process, while the final chapter will explain the potential prioritization schemes for future efforts.

B. Identification of Potential Enhancements

To identify potential enhancements to the *AMedP-8(C)* methodology for the 2013 review, the IDA research team reviewed the recommendations of the four prior annual reviews. Only proposed improvements that have not already been implemented and described in a previous section of this document ("Past Reviews and Subsequent Work Programs") will be included in the current analysis. Additional topics were identified during the course of recent analyses by the IDA research team and through a review of the assumptions and limitations of *AMedP-8(C)*. In total, this process yielded the following 14 potential enhancements (or in one case, a recommended analysis of alternatives that could lead to an enhancement), which will be discussed in the subsequent sections of this document.

1. Use data pooling method to select dose-response data
2. Conduct comparative analyses of alternate aerosol inhalation models
3. Extend the current *AMedP-8(C)* methodology to estimate civilian casualties
4. Extend the current *AMedP-8(C)* methodology to estimate psychological casualties
5. Refine current human response model parameters with newly acquired data
6. Develop human response model parameters for additional chemical or biological agents in the same class as agents currently modeled

7. Develop human response model parameters for additional chemical or biological agents in a different class than agents currently modeled
8. Include toxic load model
9. Expand Susceptible, Exposed and infected, Infectious, Removed, and Prophylaxis efficacious (SEIRP) model to include operational and medical restrictions and improve extension to Ebola and Marburg
10. Develop human response model parameters for additional radiological agents
11. Include radiation dose protraction
12. Include cloudshine effects for radioactive fallout casualty estimates
13. Develop human response model parameters for additional immediate nuclear effects
14. Model synergism for combined nuclear injuries

C. Assessment of the Impact and Level of Effort for Identified Enhancements

After identifying a number of potential improvements to the *AMedP-8(C)* methodology, the IDA team heuristically assessed their implications by ranking their impact and the level of effort required to implement them on an ordinal three-point scale (high, medium, or low). The purpose of the two ratings is to frame the costs and benefits of implementing various potential enhancements in a way that allows the sponsors to compare alternatives and select a strategy for prioritizing future enhancements to the methodology. Four possible prioritization schemes based on a matrix of the potential enhancements will be discussed in the next chapter.

For these assessments, level of effort was defined as a proxy for the time and monetary costs associated with the research and implementation of the proposed enhancement by the IDA team. In general, higher effort enhancements to the methodology require more time and manpower to carry out than lower effort enhancements. Impact was defined as the effect of the proposed enhancement on the methodology's utility to its users.

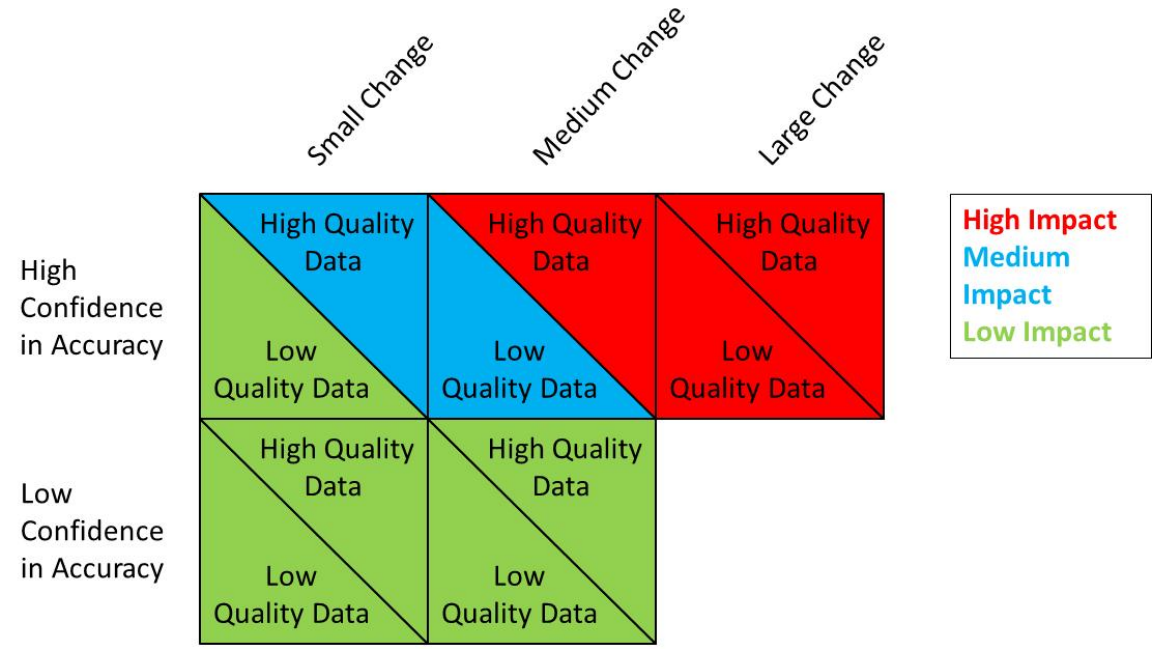
AMedP-8(C) lists a number of the users of its methodology and describes how they utilize casualty estimates to carry out their responsibilities:

> Medical planners use casualty estimates to identify medical requirements for each role of medical care. These requirements may include pharmaceuticals, medical devices, medical supplies, bed types, and personnel specialties. … Logistics planners use casualty estimates to determine logistical requirements, both medical and non-medical, necessary for the management of CBRN casualties. … Operational

> planners use casualty estimates to estimate unit capability for evaluating courses of action resulting from variations in a number of parameters such as physical protection, medical countermeasures, and avoidance. … Personnel planners or managers use casualty estimates to determine personnel replacement requirements necessitated by death or injury following a CBRN event.[11]

The effect of the proposed enhancement on the utility of the methodology to these users is a function of the magnitude of (1) the difference between casualty estimates with and without the enhancement, (2) the IDA team's confidence that the enhancement would increase the accuracy of the casualty estimate given high quality data, and (3) the quality of the data availability to model the enhancement. This is represented visually in Figure 2 in which the final impact rating (high, medium, or low) is indicated by color (red, blue, or green, respectively). As an example, the blue triangle in the middle column signifies that an enhancement to the methodology that is estimated to result in a medium change in the magnitude of the casualty estimate, for which the IDA team has high confidence that the accuracy of the casualty estimate would be improved given high quality data, and for which there is estimated to be low quality data, would be a medium impact enhancement.

[11] NATO, *AMedP-8(C)*, 1–16.



Note: Small vs. medium vs. large change = the estimated magnitude of change in the casualty estimate; high vs. low confidence in accuracy = the IDA team's confidence that the enhancement will increase the accuracy of the casualty estimate given high quality data; high vs. low quality data = the estimated quality of the data available to model the enhancement.

Figure 2. Estimated Impact of a Potential Enhancement to the *AMedP-8(C)* Casualty Estimation Methodology

Some enhancements to the methodology, namely adding the capability to estimate casualties for new agents, will result in casualty estimates that have no baseline for comparison since the methodology could not previously estimate those casualties. In these cases, the magnitude of change is defined as large, and the IDA team will always have high confidence that the new casualty estimates will be more accurate than no estimates. Since the only enhancement assigned a large magnitude is the addition of new agents, the combination of a large change in magnitude and low confidence never occurs, and the associated box is omitted from Figure 2. All enhancements other than the addition of new agents fall in the leftmost four boxes in Figure 2.

The impact and effort ratings provided in this document are estimates; the actual values, once the analyses are initiated or the enhancements implemented, may be either higher or lower than the qualitative values provided.

1. Enhancements Affecting Multiple Agent/Effects Models

a. Use Data Pooling Method to Select Dose-Response Data
Impact: Low Effort: Medium

A method of pooling similar dose-response data from multiple species or routes of exposure, described for both brucellosis and Q fever,[12] is potentially applicable to all CBRN agents and effects. In contrast to the *AMedP-8(C)* method of relying on a hierarchy of data sources, the data pooling method compares all the potential sources of exposure data (i.e., various species and routes of exposure). If certain criteria are met and two or more data sets are considered similar enough, then they can be combined to create a model based on more data points. While recognizing the benefits of developing a model from an expanded dataset, the IDA team has low confidence that combining data from vastly different species (e.g., non-human primates and mice) would increase the accuracy of the casualty estimate, even for datasets that pass the statistical tests to be pooled. Before implementing this enhancement, the IDA team would consult with toxicology and infectious disease experts to determine whether this makes sense physiologically.

Given that this approach is supported by experts, it has the potential to increase the number of data points underlying nearly all the human response models in *AMedP-8(C)*. Nevertheless, the IDA research team expects that this will result in only a minor change to the casualty estimates. The data currently underlying the *AMedP-8(C)* models are from the sources and exposure routes most relevant to estimating human response to an inhalation exposure, so these would remain the baseline to which other potential datasets

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[12] Teske et al., "Animal and Human Dose-Response Models for *Brucella* Species," *Risk Analysis* 31 (2011): 1576–1596; Sushil B. Tamrakar et al., "Dose-Response Model of *Coxiella burnetii* (Q Fever)," *Risk Analysis* 31, no. 1 (2011): 120–128.

would be compared. Since the additional data that meet the criteria to be pooled would, by definition, be similar to the baseline data, pooling would likely result in models similar to those already published, with narrower confidence intervals due to the larger total dataset. It is also possible that the models would remain the same because no additional data fit the criteria for pooling.

The impact of using the data pooling method to select dose-response data is estimated to be low, because the magnitude of the change in the casualty estimate is estimated to be small, the IDA team's confidence that the enhancement would increase the accuracy of the casualty estimate given high quality data is low, and the quality of the available data is estimated to be high.

Implementing the data pooling method as described for brucellosis and Q fever (i.e., testing data from multiple species and routes of exposure) would be a medium effort task for each agent/effect. Many dose-response datasets likely exist for small animal models (e.g., mice, rats, guinea pigs) that were not considered in the current methodology. During the development of the *AMedP-8(C)* human response models, the IDA team first sought out human and then non-human primate data. Only if those were unavailable did the IDA team then seek out data from other animal models that ranked lower in the hierarchy of data sources described in *AMedP-8(C).*

For each CBRN agent and effect, adopting the data pooling method would require identifying additional data sources and then systematically comparing each dataset to the human and non-human primate datasets currently used in *AMedP-8(C)*. Since small animal models are less expensive than non-human primate models, there may be significantly more studies on these species. One way to reduce the level of effort would be to limit the potential datasets to human and non-human primate data but to consider additional routes of exposure besides inhalation.

b. Conduct Comparative Analyses of Alternate Aerosol Inhalation Models
Impact: Low Effort: High

Another analysis that could lead to potential enhancements to the *AMedP-8(C)* methodology is to compare the dose-response models currently in *AMedP-8(C)* to alternative methods of estimating the probability of infection or death given an inhaled dose. Anthrax models that consider within-host processes, such as germination and clearance of spores, were identified in the 2012 review.[13] By modifying the parameter

[13] Judy Day, Avner Friedman, and Larry S. Schlesinger, "Modeling the Host Response to Inhalation Anthrax," *Journal of Theoretical Biology* 276, no. 1 (2011): 199–208; Judy Day, Avner Friedman, and Larry S. Schlesinger, "Supplementary Materials for Modeling the Host Response to Inhalation Anthrax," *Journal of Theoretical Biology* 276, no. 1 (2011), DOI: 10.1016/j.jtbi.2011.01.054. Joseph R. Egan et al., "Re-Assessment of Mitigation Strategies for Deliberate Releases of Anthrax Using a Real-Time Outbreak Characterization Tool," *Epidemics* 2, no. 4 (2010): 189–194.

values, these models could potentially be applied more widely to include other agents. Analyses comparing the current dose-response models to alternatives that explicitly consider the internal interactions of inhaled particles with the host could reveal significant differences in the resulting casualty estimates (a medium change), but the IDA team has low confidence that the added complexity of other models would increase the accuracy of the casualty estimates. In addition, it is unlikely that the type of data needed to specify the parameters for some new models are available for each agent. For example, many of the parameter values for the anthrax models were estimated in the absence of experimental data. For these reasons, the estimated impact of conducting comparative analyses of alternate aerosol inhalation models is low.

The process of comparing the alternate aerosol inhalation models to those already in *AMedP-8(C)* requires several steps. First, the IDA team should conduct a literature search to identify additional models of aerosol particle inhalation for comparison. The team then needs to understand the models, their inputs and outputs, how the parameters function in each model, and how parameter values may need to be modified to be consistent with the assumptions in *AMedP-8(C)*. This might require replicating the results of the published models to ensure comprehension.

Once the models are well understood, the next step is to develop criteria to judge various features of the models to determine which is best. Whatever the criteria, they should allow for the assessment of some differences between the competing alternatives so that they are useful for decision making. The IDA team would then choose a representative agent to determine how and by how much the various models differ. Finally, the team would use the predetermined criteria to judge which model best suits the casualty estimation methodology. The IDA team considers this process of identifying and understanding the alternate models, developing criteria by which to compare them, and evaluating their suitability by those criteria when applied to a representative agent to be a high effort task.

c. Extend the Current *AMedP-8(C)* Methodology to Estimate Civilian Casualties

Impact: Medium Effort: Medium

Planners may benefit from the ability to model civilian casualties from weapons of mass destruction because even CBRN attacks aimed at military targets are likely to produce some civilian casualties in certain settings (e.g., urban warfare). Moreover, even if a nation models military and civilian casualties as two separate patient streams with distinct medical facilities and resources, it is likely that in a mass casualty situation, there would be considerable overlap of resources, and estimates of the total number of casualties (both military and civilian) would be informative.

Currently *AMedP-8(C)* assumes individuals are normally healthy. As a result, the methodology "may not be suitable for estimating casualties among civilian populations, since civilian populations may be more susceptible to CBRN agents or effects."[14] This increased susceptibility would result in underestimating the number of individuals that become injured or die if the *AMedP-8(C)* methodology were applied to civilians without modification. Furthermore, for chemical agents, the methodology assumes that the population is comprised of 70 kilogram (kg) men. Representing the masses of the civilian population as a distribution rather that this fixed value would likely improve the casualty estimates for chemical agents.

The IDA team has high confidence that civilian body mass distributions are available (at least for the U.S. population), so scaling the toxicity of chemical agents to different size individuals should be possible. At the very least, average weights are available by nation, so a single value other than 70 kg could be chosen to represent the civilian population. On the other hand, the team has low confidence that data are available to quantify the increased susceptibility of certain subpopulations (pediatric, geriatric, or immune-compromised) exposed to CBRN agents and effects. In general, data from these subpopulations were excluded from the *AMedP-8(C)* human response models, but in some cases the models (particularly for biological agents) were derived from historical outbreaks among the civilian population, since those outbreaks were often the best available source of data on symptoms, severity, and duration of illness.

The impact of modeling the increased susceptibility and response variability in a civilian population is estimated to be a medium impact enhancement due to the estimated medium change in the casualty estimates, the high confidence that the accuracy of the casualty estimates would be improved, and the low quality data available to model the enhancement.

Extension of the *AMedP-8(C)* methodology to civilian populations would have three components. First, the IDA team would review the parameters incorporated within the human response models to determine which are derived from general population data and can be used directly in a civilian variant. At the same time, the team would review any parameters derived from animal models and scaled or applied directly to humans to determine the extent to which characteristics of a military population were considered in the scaling or application, and would modify the parameters to reflect the characteristics of a civilian population.

Second, in cases where special subpopulations—like pediatric, geriatric, or immune-compromised—have unique or exaggerated responses, IDA would need to collect data to characterize that response within the individual agent models.

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[14] NATO, *AMedP-8(C)*.

Third, in the absence of data on special populations, the IDA team could derive planning factors and heuristics for modifying *AMedP-8(C)* casualty estimates from a review of the general literature on infectious disease, toxic substances, radiation, etc. Analogous diseases and conditions would be used to determine the general extent to which casualty estimates would change given a civilian population.

The estimated level of effort to identify the parameters, planning factors, and heuristics for modifying current *AMedP-8(C)* human response model parameters so that they are applicable to civilian populations is medium. Due to the significant potential changes to the casualty estimates, but the low confidence that some of the necessary data will be available and high-quality, the IDA team estimates this enhancement to have a medium impact on the methodology's utility to its users.

d. Extend the Current *AMedP-8(C)* Methodology to Estimate Psychological Casualties

Impact: Medium Effort: High

A quantitative model to predict the number of psychological casualties from CBRN threats has yet to be developed. This is a major limitation of most casualty estimation tools, including *AMedP-8(C)*, since estimates of psychological casualties would allow planners to anticipate their impact on triage, demands on the medical system, and the effectiveness of military units. Psychological casualty estimates specific to each type of CBRN agent or effect would help planners more accurately predict total casualties and the resources required to manage them. Separate models may be appropriate for military and civilian populations, and both may be of interest to military planners if the two populations might be expected to share medical resources in the case of a CBRN emergency.

Psychological casualties have been known to account for a non-trivial fraction of casualties from conventional (non-CBRN) warfare. For instance, it was estimated that 5–30% of the total United Kingdom (UK) casualties evacuated from battle areas in all theatres in World War II were psychological casualties.[15] Many factors of fighting in a CBRN environment may contribute to the risk of warfighters becoming psychological casualties: the additional stresses caused by wearing mission oriented protective posture (MOPP) gear, the uncertainty in knowing if they have already been exposed, the potential scale of casualties, and the uncertain outcome of treatment.

The IDA team estimates that including psychological casualties could significantly change the final casualty estimates (a medium change), and given high quality data, the IDA team has high confidence that this enhancement would increase the accuracy of the

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[15] Edgar Jones and Simon Wessely, "Psychiatric battle casualties: an intra- and interwar comparison," *British Journal of Psychiatry* 178 (2001): 242–247.

casualty estimates. Since the IDA team estimates that the available data for developing a model for psychological casualties are of low quality, it has estimated this to be a medium impact enhancement.

As outlined in the 2009 review,[16] the extension of the *AMedP-8(C)* methodology to estimate psychological casualties, if it is even feasible with currently available data, would require a high level of effort. As a first step, since psychological casualty definitions are continuing to evolve, it is essential to reach a consensus on terminology. Once definitions have been established, psychological casualties would need to be appropriately characterized to differentiate those that would impact the acute casualty estimate from those that might be delayed beyond the period of interest to *AMedP-8(C)*.

Next, it would be necessary to develop a correlation of the types of psychological casualties of interest to the different classes of CBRN agent or effect, and potentially to the populations at risk. To the extent possible, the IDA team would need to collect data to characterize that relationship for each CBRN class or agent model. The number of psychological casualties may be a function of not only the type of attack and whether casualties were military or civilian but also the attack size and the size of the population at risk. If limited data are available, it may be necessary to extrapolate across CBRN agents and effects.

Finally, the IDA team would have to derive and accredit modifications to the *AMedP-8(C)* casualty estimation methodology to quantify psychological casualties. Given that the previous steps had been successfully completed, this is primarily a requirement for analysis, documentation, and presentation.

e. Refine Current Human Response Model Parameters with Newly Acquired Data

Impact: Medium Effort: Medium

Since the publication of *AMedP-8(C)* and the subsequent chemical and biological agent human response models, IDA has identified a number of new data sources that could contain useful information to update various *AMedP-8(C)* human response model parameters. As detailed in the 2012 review,[17] data are available that could impact the anthrax, botulism, brucellosis, glanders, plague, Q fever, and smallpox models. In addition, IDA developed the Q fever, SEB, and tularemia models with the understanding that they would be updated when IDA gained access to the medical records of MRVs from Operation Whitecoat, a research program carried out by the U.S. Army between 1955 and 1973 in which MRVs were exposed to bacteria and viruses to study the effects

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16 Curling, LaViolet, and Burr, *2009 Report on the Extension of AMedP-8(C)*.

17 LaViolet, Burr, and Curling, *2012 Review on the Extension of AMedP-8(C)*.

of the medical countermeasures against potential biological warfare agents.[18] IDA is still pursuing access to the data on human infectivity and symptom progression following exposure to these agents.

Additionally, IDA intends to review information from the System for Evaluation and Archiving of Radiation Accidents based on Case Histories (SEARCH) radiation effects database and the international Group to Link nonhuman Primate and Human radiation effects (GLiPH) to update or validate the *AMedP-8(C)* radiological human response models. In a similar way, the IDA team could potentially use some recently published dose and time distributions for acute lethal and nonlethal effects of radiation to validate the current *AMedP-8(C)* radiation methodology. These distributions relating dose to the onset of vomiting, agranulocytosis, and death were derived from radiation exposure accidents at the Mayak Production Association in Russia.[19]

Although the IDA team has identified a considerable quantity of new information that could be used to update *AMedP-8(C)*, the existing models are already built on a large body of reputable data. Little of the new material is expected to refute current data, and most is likely to support and refine the existing models. For this reason, it is estimated that there will be few significant changes to the human response model parameters and that there will be a small change to the casualty estimates. The IDA team determines that the addition of high quality data will improve the accuracy of the casualty estimates, and it estimates the quality of the new data to be high relative to the data in existing models.[20] Therefore, the IDA team estimates the final impact on the utility of the methodology to its users to be medium.

AMedP-8(C) was intentionally developed to be easily updated as new data became available. For biological agents, the human response models are divided into independent submodels to allow for easy modification of individual parts, and nearly all of the

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18 Dan Crozier, "History of the Commission on Epidemiological Survey," in *The Armed Forces Epidemiological Board: The Histories of the Commissions*, ed. Theodore E. Woodward, 209–58 (Washington, DC: Department of Defense, Office of the Surgeon General, U.S. Army, Borden Institute, 1994).

19 S. V. Osovets et al., "Direct and indirect tasks on assessment of dose and time distributions and thresholds of acute radiation exposure," *Health Physics* 102, no. 2 (2012): 182–95; S. V. Osovets et al., "Assessment of risks and dose thresholds for some effects of acute exposure," *Health Physics* 100, no. 2 (2011): 176–84.

20 While this document rates the quality of data that are *now* available relative to the quality of data that *were* available, an upcoming IDA document, D-4799, addresses the hypothetical data that one would like to use as the basis of human response models. The confidence assessment portion of the recommendations in D-4799 is based on a comparison of the data that were actually used in the development of each model to the data that would ideally be used to develop the model, if such data existed. Sean M. Oxford and Audrey C. Kelley, *Comparison of Chemical and Biological Human Response Parameter Values in NATO and U.S. Doctrine*, draft IDA Document D-4799 (Alexandria, VA: Institute for Defense Analyses, 2014).

parameters are located in the document's annexes to simplify the process of documenting changes.

Although the IDA team has already collected most of the newly identified publicly available data, the MRV datasets require special access and will likely need to be examined and transcribed manually, a lengthy and labor-intensive process. The IDA team has also reached out to administrators of the SEARCH database to request access to their data. Assuming IDA can obtain access to these additional sources of information, the next steps are to extract the relevant data, assess their quality relative to existing data, and incorporate the high quality data into existing human response models. Lastly, the analysis would need to be documented, validated, and published. Considering the work associated with collecting the MRV data, the IDA team assessed updating existing human response models with new data to be a medium effort task.

f. Develop Human Response Model Parameters for Additional Chemical or Biological Agents in the Same Class as Agents Currently Modeled
Impact: Medium Effort: Low

In developing *AMedP-8(C)*, the IDA team, with direction from NATO, decided to model the highest threat agents within each agent class. For instance, it selected GB and VX to represent the G-series and V-series of nerve agents, respectively. Likewise the team chose HD to represent the class of mustard agents, and serotype A as the most likely threat among the seven known serotypes of botulinum toxin. Some lower threat agents similar to currently modeled agents have been developed for wartime use, and if users of the *AMedP-8(C)* methodology perceived them as likely battlefield threats, it would be beneficial to include the capability to estimate casualties from those agents.

Currently, planners could use the casualty estimate from an agent already modeled in *AMedP-8(C)* as an approximation of a new agent in the same class. Since the mechanisms of action for agents within the same class are often alike, there may be little difference between the human response parameters between agents. The likely differences would be in the toxicity or infectivity values, which are estimated to result in small variations between the casualty estimates of agents in the same class. Even for soman (GD), a G-series nerve agent that does not respond to treatment due to its rapid aging, planners could produce an approximate casualty estimate by modeling GB without treatment. The IDA team has high confidence that the casualty estimates from a model specific to a new agent would be more accurate than those from a model of a similar agent, and it estimates that the quality of the data available to implement this enhancement is high, even if they consist only of toxicity or infectivity values. Therefore, the IDA team estimates the impact of developing human response models for additional agents in the same class as currently modeled agents to be medium.

The effort required to model additional chemical and biological agents depends on the availability of information. There may be little human response data available on the lower priority agents from the same class as currently modeled agents. If this is the case, then much of the human response modeling will be done by analogy to existing agents, and the IDA team estimates that the effort required to do so will be low. For instance, if toxicity is the only distinguishing feature between a currently modeled chemical agent and a related agent that is supported by data, then dose ranges for the new agent will need to be defined, while other parameters will remain the same.

On the other hand, if a significant amount of information is available that distinguishes a new agent from a similar agent already modeled, parameters for each submodel will need to be quantified just as for any new agent not yet modeled in *AMedP-8(C)*. In this case, the similar agent would effectively be considered an agent unrelated to those already in *AMedP-8(C)* and would be captured under the enhancement in the next section.

g. Develop Human Response Model Parameters for Additional Chemical or Biological Agents in a Different Class than Agents Currently Modeled
Impact: High Effort: Medium

Only a limited number of chemical and biological agents are modeled according to the *AMedP-8(C)* methodology. The purpose of *AMedP-8(C)* is to make it possible to estimate casualties from CBRN threats that are likely to be encountered on the battlefield. In the absence of a comprehensive list of chemical and biological agents ranked by the likelihood of their use, the 2009 review compiled lists of agents of concern to various government and international bodies.[21] The agents modeled in *AMedP-8(C)* and in subsequent follow-on efforts were those specified most often on various CBRN threat lists and, therefore, the greatest perceived threats. Additional threats to consider modeling in the future include cholera (on seven lists), Lassa fever (on six lists), Crimean-Congo hemorrhagic fever (on six lists), ammonia (on five lists), O-chlorobenzylidene (CS) gas (on four lists), and 3-quinuclidinyl benzilate (BZ) (on four lists). Agents that have been modeled in the CUD (e.g., Rift Valley fever, *E. coli*, typhoid) are also candidates for inclusion.

Currently, the methodology has zero utility for planners that need to estimate casualties resulting from an attack with a new agent unlike those already included. As shown in Figure 2, adding the capability to estimate casualties for new agents that are considered potential threats is a high impact enhancement. The magnitude of the change in casualty estimates is considered large for new agents that planners previously could

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[21] For the full list of agents considered and the reference lists from which they came, see Appendix A of Curling, LaViolet, and Burr, *2009 Report on the Extension of AMedP-8(C)*.

not model, and the IDA team has high confidence that casualty estimates derived from new agent models based on high quality data are better than no casualty estimates. The estimated quality of the data available to implement this enhancement, which would depend on the specific agents under consideration, does not affect the final impact rating.

In general, those agents assessed to be higher threats tend to be higher research priorities at defense laboratories. The controlled toxicity and pathology studies that produce the types of data useful for determining human response modeling parameters are, therefore, less likely to be performed for those agents not yet modeled according to the *AMedP-8(C)* methodology. Nevertheless, chemical agents and naturally-occurring diseases may be studied elsewhere for industrial or commercial uses or for public health reasons. Considering the variability in the quality and availability of the data needed to generate human response models for various additional agents, the IDA team determined this to be, on average, a medium effort task for a given agent.

2. Enhancements Affecting Only Chemical Agent Models

a. Include Toxic Load Model

Impact: Low Effort: Low

The physiological effects of many chemical agents depend on not only the total dose received by the body but also the amount of time over which it was received. Due to the body's natural ability to clear chemicals over time, a shorter exposure is typically more damaging than a longer exposure resulting in the same total dose. *AMedP-8(C)* currently uses Haber's law, which assumes that the total dose results in the same physiological response regardless of the exposure time. A possible alternative to Haber's law that considers the body's ability to clear chemicals over time is a toxic load model.

IDA recently completed an informal analysis comparing Haber's law to four variants of a toxic load model supported by enough high quality data to quantify the necessary parameters. This comparison revealed a medium change in the magnitude of the casualty estimates; Haber's law predicts more casualties with more severe injuries than the toxic load models. The IDA team has low confidence that the toxic load models produce more accurate casualty estimates than those currently output by *AMedP-8(C)*, as none of the toxic load models considered has been verified as a better model for realistic scenarios with time-varying agent concentrations. For defensive planning purposes, the more conservative estimates based on Haber's law may be more appropriate. Due to these factors, the IDA team assesses replacing Haber's law with one of the four toxic load models investigated to be a low impact enhancement. It may be possible to incorporate both Haber's law and a toxic load model into the *AMedP-8(C)* methodology and either output two casualty estimates or allow the choice to be a matter of national opinion,

although this disregards the advantages of having a common CBRN casualty estimation planning methodology.

Estimated toxic load exponents are available for all of the chemical agents modeled in *AMedP-8(C)*, so the transition from Haber's law to an existing toxic load model is estimated to be a low effort task. The IDA team would need to establish some decision criteria and then select a toxic load model variant (e.g., integrated concentration, average concentration, concentration intensity, or peak concentration toxic load model). Next the output from the toxic load model would need to be converted to an "equivalent prompt dosage" value in order to use the same dosage ranges that are currently in *AMedP-8(C)*, but this calculation is known and straight-forward.

3. Enhancements Affecting Only Biological Agent Models

a. Expand SEIRP Model to Include Operational and Medical Restrictions and Improve Extension to Ebola and Marburg

Impact: High Effort: Medium

The *AMedP-8(C)* methodology uses the SEIRP model to estimate casualties from contagious diseases. In addition to smallpox and plague, which are included in *AMedP-8(C)*, the IDA team has also modeled Ebola and Marburg, although the SEIRP model implementation for those diseases has some limitations. First, Ebola and Marburg survivors should progress through the stages of illness at different rates than non-survivors, but the time spent in a given stage in the SEIRP model is the same for all individuals. Second, the SEIRP model has only two stages of illness, whereas Ebola and Marburg survivors should pass through three distinct stages. As a result, the SEIRP model does not estimate the time at which survivors recover at the end of the third stage of illness. Third, the manifestation of both diseases may vary based on the route of exposure. In the case of an aerosol attack, individuals would be initially exposed via inhalation. The subsequent spread of the diseases is thought to be through direct contact with an infected individual's blood or other bodily fluids rather than through aerosol transmission. Therefore, it would be useful for the SEIRP model to be able differentiate between primary and secondary cases of infection, so they could be modeled differently.

Another modification that would affect not only Ebola and Marburg, but all contagious diseases, is incorporating operational and medical restrictions (such as isolation, quarantine, and other restrictions of movement [RM]) into the SEIRP model, which is currently able to reflect only the population structure that was in place during the historical outbreak from which the model parameters were derived. However, the ability to explicitly vary the structure of the population within the model would allow the users of the methodology to compare the casualty estimates resulting from different RM strategies.

The IDA team estimates that the magnitude of difference between the casualty estimates with and without the enhancements described above would be medium and has high confidence that the new casualty estimates would be more accurate. It also estimates that the quality of data available to implement these enhancements is high. For that reason, the IDA team deems addressing the limitations of the Ebola and Marburg models and allowing the inclusion of operational and medical restrictions of movement to be high impact improvements to the methodology.

Modifying the SEIRP model used in *AMedP-8(C)* to incorporate these enhancements would be a medium effort task. The framework for an SEIRP model that allows for control measures to be modeled in a structured population is described in a 2006 article for a severe acute respiratory syndrome (SARS) outbreak in Taiwan in 2002 and 2003.[22] The IDA team would need to adapt this model to apply it to the diseases modeled in *AMedP-8(C)* and then derive the necessary parameter values, many of which could be used directly from the existing SEIRP implementation. These adaptations would include modifying the underlying equations to vary the rates at which the survivors and non-survivors progress through the stages of illness for Ebola and Marburg. An additional challenge in transitioning to the new model would be testing the IDA team's understanding of the complex mathematics through implementation, which unlike the current model, could not be implemented in Excel and would require a more sophisticated software package, such as Mathematica.

4. Enhancements Affecting Only Radiological Agent Models

a. Develop Human Response Model Parameters for Additional Radiological Agents

Impact: High **Effort: Low (High for neutron emitters)**

The radioisotopes currently modeled in *AMedP-8(C)* as possible radiological dispersal device (RDD) components are ^{60}Co, ^{90}Sr, ^{131}I, ^{137}Cs, ^{192}Ir, ^{238}Pu, and ^{241}Am. As stated in the *AMedP-8(C) Technical Reference Manual*, these radiological agents are included because they "have the potential for producing an acute radiation injury (overt symptoms within the time period of interest) and have a credible likelihood of battlefield exposure."[23] However, they are not the only radioactive sources that exist in sufficient quantities to result in acute injuries if used in an RDD.

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22 John N. Bombardt, "Congruent Epidemic Models for Unstructured and Structured Populations: Analytical Reconstruction of a 2003 SARS Outbreak," *Mathematical Biosciences* 203, no. 2 (2006).

23 Curling et al., *Technical Reference Manual: AMedP-8(C)*.

A 2003 International Atomic Energy Agency (IAEA) report[24] ranked practices using radioactive source materials (e.g., radioisotopic thermoelectric generators, sterilization and food preservation irradiators) according to the potential danger they posed to human health and safety. The authors grouped practices into the five categories in Table 1 (reproduced from the IAEA report), with categories 1 through 5 described as "personally extremely dangerous," "personally very dangerous," "personally dangerous," "unlikely to be dangerous," and "not dangerous," respectively.

[24] International Atomic Energy Agency (IAEA), *Categorization of Radioactive Sources: Revision of IAEA-TECDOC-1191, Categorization of Radiation Sources*, IAEA-TECDOC-1344 (Vienna, Austria: IAEA 2003).

Table 1. Categorization of Common Practices Utilizing Radioactive Sources (Reproduced from Page 8 of IAEA-TECDOC-1344)

Category	Categorization of Common Practices[a]	Activity Ratio[b] (A/D)
1	• Radioisotope thermoelectric generators (RTGs) • Irradiators • Teletherapy • Fixed, multi-beam teletherapy (gamma knife)	A/D ≥ 1000
2	• Industrial gamma radiography • High/medium dose rate brachytherapy	1000 > A/D ≥ 10
3	• Fixed industrial gauges – Level gauges – Dredger gauges – Conveyer gauges containing high activity sources – Spinning pipe gauges • Well logging gauges	10 > A/D ≥ 1
4	• Low dose rate brachytherapy (except eye plaques and permanent implant sources) • Thickness/fill-level gauges • Portable gauges (e.g., moisture/density gauges) • Bone densitometers • Static eliminators	1 > A/D ≥ 0.01
5	• Low dose rate brachytherapy eye plaques and permanent implant sources • X-ray fluorescence devices • Electron capture devices • Mossbauer spectrometry • Positron Emission Tomography (PET) checking	0.01 > A/D ≥ Exempt[c]/D

Source: IAEA, *Categorization of Radioactive Sources: Revision of IAEA-TECDOC-1191, Categorization of Radiation Sources*, IAEA-TECDOC-1344 (Vienna, Austria: IAEA 2003).

Notes:

[a] Recognizing that factors other than activity over danger (A/D) have been taken into consideration (see Section 2.3.6 of IAEA-TECDOC-1344).

[b] This column can be used to determine the category of a source, based purely on A/D. This may be appropriate if, for example, the practice is not known or is not listed; sources have a short half-life and/or are unsealed; or sources are aggregated (see Section 3.3 of IAEA-TECDOC-1344).

[c] Exempt quantities are given in Schedule I of the *Basic Safety Standards*.[25]

[25] Food and Agriculture Organization of the United Nations, International Atomic Energy Agency, International Labour Organization, OECD Nuclear Energy Agency, Pan American Health Organization, World Health Organization, "International basic safety standards for protection against ionizing radiation and for the safety of radiation sources, safety series no. 115," (Vienna, Austria: IAEA, 1996).

In general, radionuclides associated with category 1, 2, or 3 practices had an activity ratio (A/D) of 1 or greater. This signifies that the activity (A) of the radioactive source was above the activity threshold considered dangerous (D). Five radiological agents with an A/D ratio of 1 or greater and therefore potentially dangerous to humans (^{75}Se, ^{99}Mo, ^{169}Yb, ^{239}Pu/Be, and ^{241}Am/Be) are not currently included in *AMedP-8(C)* (all currently modeled radiological agents are associated with A/D ratios greater than 1). Adding the capability to estimate casualties from these new radiological agents would greatly increase the utility of the methodology to a planner anticipating attacks with any of these agents. The IDA team rates this as a high impact enhancement since the magnitude of change in the casualty estimates is defined to be large since no estimates are currently possible for these agents, the IDA team has high confidence that this enhancement will improve the accuracy of the casualty estimates, and high quality data are available for most of the isotopes of interest. Even for the agents for which low quality data are available, the impact is still estimated to be high.

The *AMedP-8(C)* radiological agent human response methodology requires the calculation of both a whole-body and a cutaneous radiation dose. For each radioisotope included in the methodology, five conversion factors are used to compute these values from skin contamination (used for the cutaneous dose calculation only), cloudshine (air immersion; modeled for RDD scenarios only), and groundshine. *AMedP-8(C)* Tables A-5 through A-7 list dose conversion factors for the currently modeled radiological agents from either *Federal Guidance Report No. 12: External Exposure to Radionuclides in Air, Water, and Soil*,[26] or *Generic Procedures for Assessment and Response during a Radiological Emergency*, IAEA-TECDOC-1162.[27]

In order to expand the number of radiation sources modeled in *AMedP-8(C)*, the five dose conversion factors specific to each new radioisotope would need to be identified. For ^{75}Se, ^{169}Yb, and ^{99}Mo, all five factors are available in the same source documents referenced above. The inclusion of these radioisotopes would, therefore, require a very low level of effort. In contrast, none of the factors are available for ^{239}Pu/Be or ^{241}Am/Be, the two neutron emitters. Factors not listed in the current references would need to be derived from other sources. Assuming the data are available to make consideration of these factors feasible, this would constitute a high level of effort.

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[26] Keith F. Eckerman and Jeffrey C. Ryman, *Federal Guidance Report No. 12: External Exposure to Radionuclides in Air, Water, and Soil*, EPA-402-R-93-081(Washington, DC: U.S. Environmental Protection Agency, 1993).

[27] IAEA, *Generic Procedures for Assessment and Response during a Radiological Emergency*, IAEA-TECDOC-1162 (Vienna, Austria: IAEA, August 2000).

b. Include Radiation Dose Protraction
Impact: Medium Effort: High

A whole-body radiation dose received over an extended time period is generally less harmful than that same dose received at a higher dose-rate because time allows for intracellular repair and tissue recovery. In fact, the risks from a low dose-rate exposure may be two to three times less than the risks from the same exposure received acutely at a high dose-rate.[28] Moreover, a low dose exposure to radiation may actually provide some protective effects against a high dose exposure hours later.[29] At present, with the exception of considering a whole-body dose protraction factor for use in determining the time to death for radiation, *AMedP-8(C)* does not consider the duration of exposure.

Incorporating radiation dose protraction would result in fewer estimated casualties and less severe injuries among those casualties, which the IDA team considers a medium change to the casualty estimates. Although the IDA team has high confidence that a model for radiation dose protraction based on high quality data would improve the accuracy of the casualty estimates, it estimates the quality of the available data to be low and, therefore, the overall impact of the enhancement to be medium.

To implement this potential modification, protracted dose models would need to be surveyed and analyzed to identify methods of calculating the "equivalent prompt dose" to a protracted dose of radiation for non-lethal endpoints. Although many investigations on protracted radiation effects studied how the median lethal dose for animals changes as a function of dose rate,[30] some data have been published on sub-lethal endpoints. One report provides values for a rate-effectiveness factor that compares high and low dose-rates required to produce the same radiation symptoms,[31] while another describes models for estimating the timing and severity of upper and lower gastrointestinal symptoms as a function of dose and dose rate.[32] While these may well serve as a starting point, the models are based on a limited amount of data and the need to modify them for use within the *AMedP-8(C)* methodology make this a high effort task.

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28 Elaine Ron, "Protraction effects in radiation studies: epidemiology," *Radiation Research* 154, no. 6 (2000): 737–38.

29 R.E.J. Mitchel, "Low Dose of Radiation Reduce Risk *In Vivo," Dose-Response* 5, no. 1 (2007) 1–10, available from the National Center for Biotechnology Information website: http://www.ncbi.nlm.nih.gov/pmc/articles/PMC2477704/pdf/hormes-05-1.pdf.

30 G. H. Anno and S. J. Baum, Effects of Protracted Ionizing Radiation Dosage on Humans and Animals: A Brief Review of Selected Investigations," (Alexandria, VA: Defense Nuclear Agency, 1990).

31 Ibid.

32 George H. Anno et al., *Biological Effects of Protracted Exposure to Ionizing Radiation: Review, Analysis, and Model Development* (Los Angeles, CA: Pacific-Sierra Research Corp., 1991).

c. Include Cloudshine Effects for Radioactive Fallout Casualty Estimates
Impact: Medium Effort: Low

Cloudshine, the radiation emitted from radioactivity in the air (also known as air immersion), is excluded from *AMedP-8(C)* for fallout scenarios (but not for RDD scenarios) because modeling the changing doses and dose rates in a fallout cloud is beyond the capability of most dispersal models. As pointed out in the *AMedP-8(C) Technical Reference Manual*, this is "a limitation of the existing hazard prediction models and not of the *AMedP-8(C)* methodology—if future hazard prediction tools are better able to model air immersion in fallout scenarios, then this limitation goes away."[33]

Without modeling cloudshine, the *AMedP-8(C)* methodology is expected to underestimate the total whole-body and cutaneous radiation doses and therefore the severity of casualties. However, cloudshine is transient and short-term, and the contribution of cloudshine relative to groundshine (radiation emitted from radioactive material on the ground) and skin contamination is likely small. The IDA team, therefore, estimates the magnitude of change between the casualty estimates to be small. At the same time, the IDA team has high confidence that including the effects of cloudshine would improve the accuracy of the resulting casualty estimates, and it estimates the quality of any data output by the dispersal model to be high. Consequently, the IDA team estimates that including cloudshine effects will have a medium impact on the utility of the methodology to the users.

The development of a hazard prediction model that can account for the difficult task of modeling cloudshine is the major impediment to incorporating cloudshine into the *AMedP-8(C)* methodology. Yet, as already mentioned, this step is external to the *AMedP-8(C)* methodology development process, and the IDA team would only add cloudshine to the methodology once this task was already completed. With the appropriate dispersal model outputs, including cloudshine in the *AMedP-8(C)* methodology would be a low effort task requiring adding another term to the calculation of the whole-body and cutaneous radiation doses from fallout.

5. Enhancements Affecting Only Nuclear Effects Models

a. Develop Human Response Model Parameters for Additional Immediate Nuclear Effects
Impact: Medium Effort: High

AMedP-8(C) currently estimates nuclear casualties that result directly from prompt nuclear radiation, blast static overpressure, and thermal fluence. Casualties from most secondary, tertiary, and indirect nuclear effects are explicitly excluded from the

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[33] Curling et al., *Technical Reference Manual: AMedP-8(C).*

methodology. Among those are casualties due to secondary blast injuries, which include both blunt and penetrating trauma caused by debris (building fragments, glass shards, stones, etc.) impacting the body. Casualties from the body being displaced by the blast winds and tumbling on the open ground or stopping abruptly against a solid object are also omitted, except for fatalities caused by tumbling. Lastly, injuries or deaths caused by building collapse, flash blindness, or burns due to secondary fires are not included.

Although currently unaccounted for in the *AMedP-8(C)* methodology, casualties from these additional immediate nuclear effects may make up a considerable portion of the total number of expected casualties following a nuclear attack, and their inclusion is estimated to have a medium effect on the final casualty estimates. In particular, blast casualties may be substantially underreported as "most blast deaths occur from the collapse of occupied buildings, or from people being blown into objects or objects impacting people."[34] Injuries from broken glass could be especially far-reaching; based on data from the nuclear detonations on Hiroshima and Nagasaki, Japan, glass breakage can be expected in an area approximately 16 times as large as the area of significant structural damage to buildings.[35] Secondary fires, which are not currently modeled, are also very common at thermal fluences generated by a nuclear detonation, so even individuals shielded from flash burns by being inside a building may become casualties.[36]

The IDA team has high confidence that considering additional nuclear effects would improve the accuracy of the casualty estimates given high quality data, but it estimates that the data available to develop human response model parameters are of low quality. As a result, the IDA team assesses the inclusion of additional nuclear effects to be a medium impact enhancement.

Secondary, tertiary, and indirect nuclear effects cause a number of casualties that are difficult to account for due to the complexity of the modeling and because they depend on the scenario (e.g., posture of individuals, building types and locations, terrain). Incorporating these effects at either the individual level or the population level poses a challenge, and the development effort would be high.

The nuclear effects currently incorporated in *AMedP-8(C)* are modeled on an individual basis. That is to say, an individual's injury severity over time is determined by the level of nuclear insult he/she is exposed to and is explicitly independent from the

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34 Cham E. Dallas, "Impact of Small Nuclear Weapons on Washington, DC: Outcomes and Emergency Response Recommendations" (paper presented at the United States Senate Hearing for the Committee on Homeland Security and Governmental Affairs titled "Nuclear Terrorism: Confronting the Challenges of the Day After," Washington, DC, 15 April 2008).

35 Brooke Buddemeier, "Reducing the Consequences of a Nuclear Detonation: Recent Research," *The Bridge* 40, no. 2 (2010): 28–38.

36 Dallas, "Impact of Small Nuclear Weapons on Washington, DC."

injury severity of other exposed individuals. To retain this determinism, the incidence of injury among everyone in the population exposed to a given set of secondary, tertiary, and indirect nuclear effects would need to be modeled as either 0% or 100%. This would be especially difficult for random effects reported at a population level that are unlikely to be at either extreme (e.g., the fractions of the population injured in a building collapse or in secondary fires). If data suggest that 50% of an exposed population would become injured by a particular secondary, tertiary, or indirect nuclear effect, it might seem natural to develop two separate injury profiles to be applied evenly among the exposed population. However, this removes the determinism, and an individual's injury severity over time is no longer independent of other exposed individuals. For these types of population-based data, the IDA team would need to redefine the population by subdividing it into groups of 0% and 100% incidence.

If the ability to track an individual's injury severity over time is not necessary, then fractional rates of incidence of injury could be used to model additional nuclear effects, although this is also a difficult approach. If there were only one injury-causing insult, then applying a fractional incidence of injury to a population would provide planners with the necessary information on the number and severity of casualties over time. However, because the population will also be exposed to the numerous other nuclear insults, it will be necessary to know which individuals sustained the injury to avoid double counting or underestimating casualties. The IDA team would need to find a way to combine the deterministic and probabilistic representations of injury.

b. Model Synergism for Combined Nuclear Injuries
Impact: Medium Effort: Medium

Individuals exposed to the radiation, blast, and thermal effects of a nuclear detonation can sustain various combinations of injuries. *AMedP-8(C)* models these combined injuries by comparing the injury severity levels over time for each of the individual insults (i.e., radiation, blast, or thermal) and selecting the maximum injury severity level at each point in time. If, for instance, an individual received radiation and thermal insults that caused, at a given time, "mild" and "moderate" injuries, respectively, then the total combined injury severity level at that time would be "moderate."

This method of combining multiple insults ignores the known synergistic effect that two simultaneous injuries can result in a total injury severity more severe than either alone. For instance, the mortality associated with thermal burns has been documented to increase when radiation injury is also present.[37] Synergistic effects of this type are not

[37] U.S. Department of the Army, *Treatment of Nuclear and Radiological Casualties*, FM 4-02.283 (Washington, DC: Government Printing Office, 2001).

currently considered in *AMedP-8(C)*, and, as a result, the methodology likely underestimates injury severity, duration, and lethality from combined nuclear effects.

Introducing synergism to the nuclear model in *AMedP-8(C)* would mean that the IDA team would need to create new combined injury profiles for each unique insult combination. The predefined set of synergistic injury profiles for combined insults would replace the rule of mapping the maximum injury severity level at any given time, since this would no longer produce an appropriate combined injury profile. The increased severity of combined injuries would have a medium effect on the magnitude of the casualty estimate: individuals may be modeled to become casualties sooner or in greater numbers (depending on the injury severity level threshold chosen), and some additional casualties may become fatalities. The IDA team has high confidence that accounting for synergistic effects would increase the accuracy of the casualty estimates, but it assesses the quality of the data available to do so as low. The impact of implementing this enhancement is, therefore, estimated to be medium.

Modeling the synergistic effects of multiple simultaneous nuclear insults is a medium effort task for the IDA research team that would first require collecting and reviewing the available data on the human response to such insults. Human data from the nuclear detonations at Hiroshima and Nagasaki, Japan, are likely insufficient for a quantitative model, but the IDA team may be able to combine these with the results of any combined nuclear injuries studies on animals to develop some basic, evidence-based rules for creating new combined injury profiles. As this topic is of concern to the experts at the Armed Forces Radiobiology Research Institute (AFRRI), the IDA research team may also be able to leverage the results of any ongoing investigations for inclusion in *AMedP-7.5(A)*. It is also possible that the quantitative data required to develop combined injury profiles do not exist, and this task would need to be postponed until further data are collected.

Assuming some data are available, the next step would be to develop combined injury profiles for as many different combinations of nuclear insults as the evidence will support. It is unlikely that the IDA team could develop more than a few of the many potential combinations of various quantities of radiation, blast, and thermal insults directly, so it would need to use the existing data to generate some interpolation and extrapolation methods or general rules (e.g., “mild” radiation plus “mild” blast or thermal injuries always result in a “moderate” combined injury). The injury profiles would also need to reflect any increased mortality and reduced time to death.

6. Summary of Estimated Impact and Level of Effort Ratings

Table 2 summarizes the estimated ratings for both the impact and level of effort for the potential enhancements to the *AMedP-8(C)* methodology described above. Justifications for each of the estimated ratings are provided in the text specific to each

enhancement in the prior sections. The table also specifies the estimates for the contributing factors to the impact rating of a given enhancement. Figure 2 defines the logic of determining the final impact rating from these factors.

Table 2. Estimated Impact and Level of Effort Ratings for Potential Enhancements to the *AMedP-8(C)* Methodology

Enhancement	Magnitude of Change[a]	Confidence in Accuracy[b]	Quality of Data[c]	Impact	Level of Effort
Dose-response data pooling method	Small	Low	High	Low	Medium
Alternate aerosol inhalation models	Medium	Low	Low	Low	High
Civilian casualties	Medium	High	Low	Medium	Medium
Psychological casualties	Medium	High	Low	Medium	High
New data for existing models	Small	High	High	Medium	Medium
New chemical or biological agents (same class as existing agents)	Small	High	High	Medium	Low
New chemical or biological agents (different class)	Large	High	Low/High	High	Medium
Toxic load	Medium	Low	High	Low	Low
SEIRP changes	Medium	High	High	High	Medium
New radiological agents	Large	High	High	High	Low/High
Radiation dose protraction	Medium	High	Low	Medium	High
Cloudshine for fallout	Small	High	High	Medium	Low
New nuclear effects	Medium	High	Low	Medium	High
Synergism for combined nuclear injuries	Medium	High	Low	Medium	Medium

[a] Estimated magnitude of change in casualty estimate (arbitrary scale) (Small, Medium, Large)

[b] Confidence that enhancement will increase accuracy of casualty estimate given high quality data (Low, High)

[c] Quality of data available to model enhancement (Low, High)

3. Prioritizing Potential Enhancements to the *AMedP-8(C)* Methodology

The previous chapter described 14 potential enhancements to the *AMedP-8(C)* methodology and rated the impact and level of effort for each as high, medium, or low. Figure 3 shows these enhancements plotted on a matrix of estimated impact versus level of effort, which not only allows decision makers to visually compare the options, but also provides a framework to prioritize them. Four prioritization schemes based on this matrix are described in this chapter.

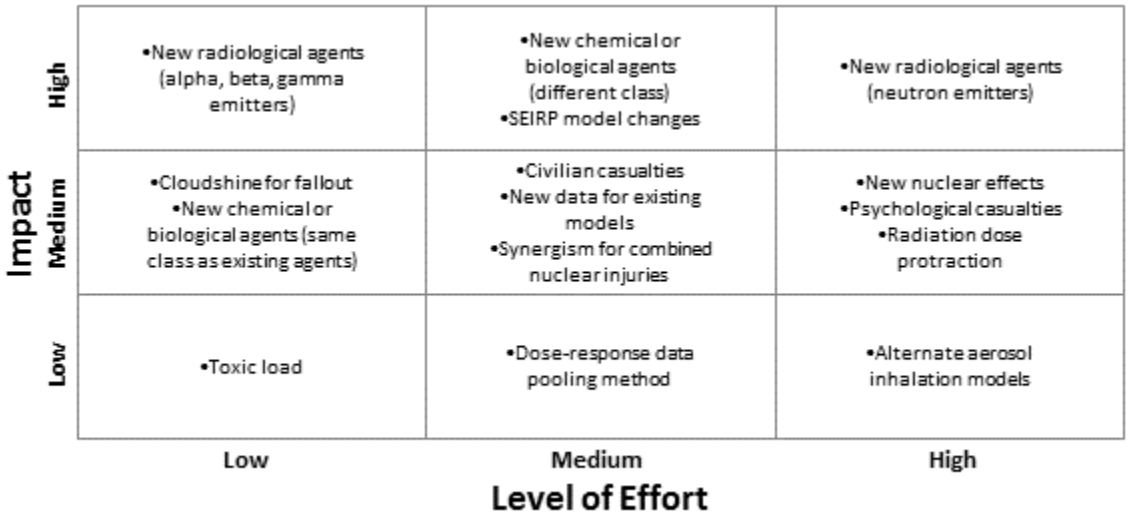

Figure 3. Potential Enhancements to the *AMedP-8(C)* Methodology Plotted on a Matrix of Estimated Impact versus Level of Effort

Figure 4 shows the first of the four systems that could be used to prioritize future efforts to extend the *AMedP-8(C)* methodology. The matrix cells are numbered by the order in which the enhancements in each cell would be implemented according to Prioritization Scheme 1 (Highest Impact). This scheme prioritizes the higher impact enhancements first, with the secondary metric being a lower level of effort.

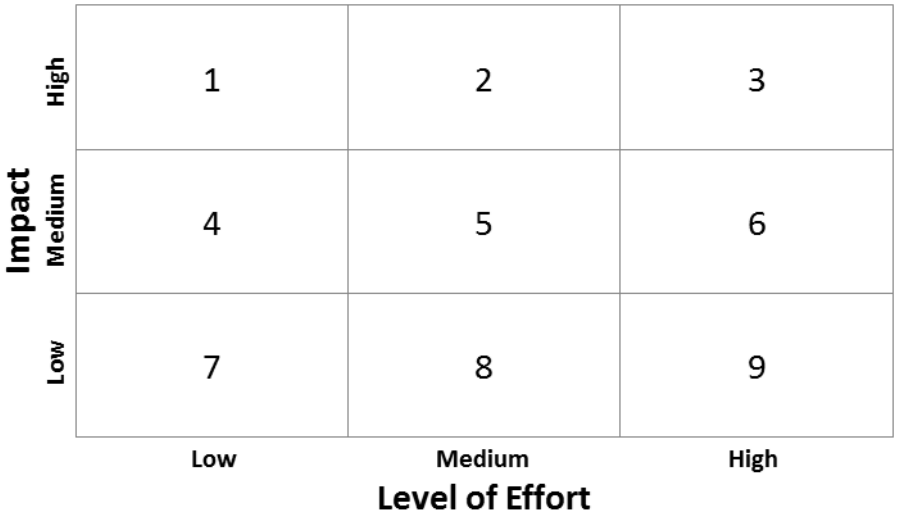

Figure 4. Prioritization Scheme 1 (Highest Impact): Preference Given to (1) Higher Impact and (2) Lower Level of Effort

An alternate method of ranking the options would be to reverse the two preferences from the first system, first prioritizing those that require the least amount of effort and then choosing the highest impact options from among those of equal effort. This approach, Prioritization Scheme 2 (Lowest Effort), is shown in Figure 5.

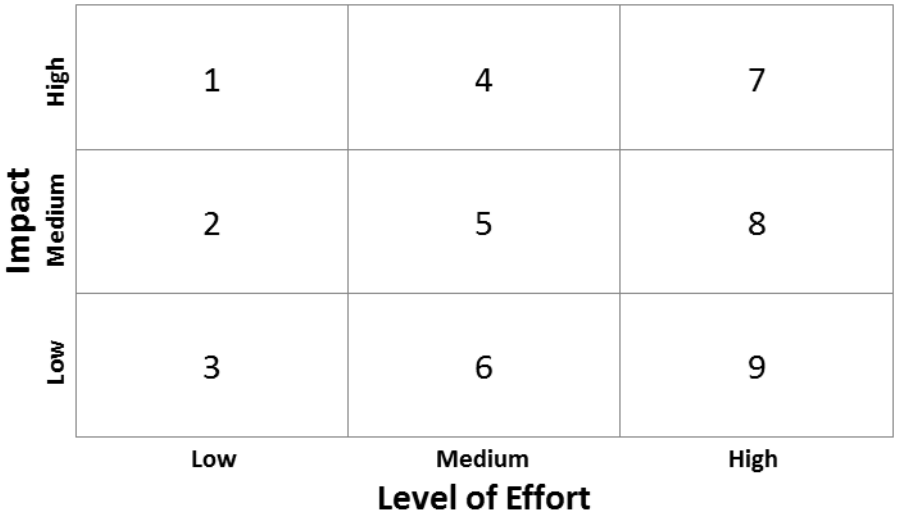

Figure 5. Prioritization Scheme 2 (Lowest Effort): Preference Given to (1) Lower Level of Effort and (2) Higher Impact

Another option would be to first prioritize enhancements that provide a high impact relative to the level of effort estimated to implement them (designated “high value”). For

example, a medium impact/low level of effort modification would be a higher priority than a high impact/high effort enhancement. Prioritization Scheme 3 (High Value, High Impact) and Prioritization Scheme 4 (High Value, Low Effort) are both variations of this approach. The former, shown in Figure 6, gives preference to those with higher impact, while the latter, shown in Figure 7, gives preference to those with a lower level of effort. In each of the four prioritization schemes described, sponsor preference or user demands would determine the order of potential enhancements contained within the same cell of the matrix.

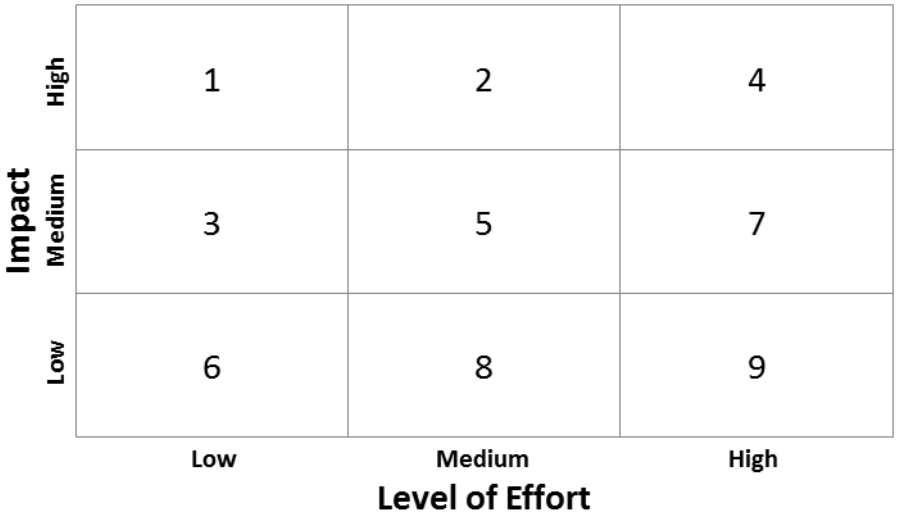

Figure 6. Prioritization Scheme 3 (High Value, High Impact): Preference Given to (1) Higher Differential between Impact and Level of Effort Rating and (2) Higher Impact

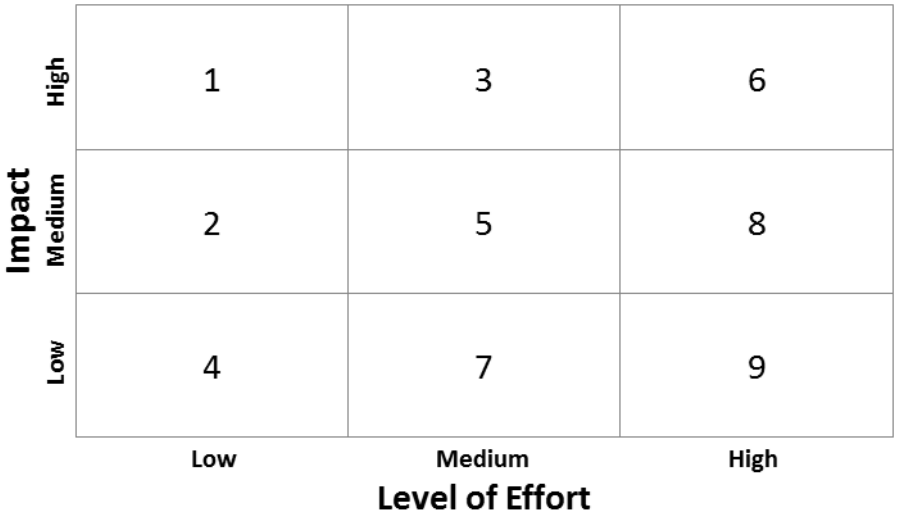

Figure 7. Prioritization Scheme 4 (High Value, Low Effort): Preference Given to (1) Higher Differential between Impact and Level of Effort Rating and (2) Lower Level of Effort

Each of the four prioritization schemes results in a different rank-order of the 14 potential enhancements to the *AMedP-8(C)* methodology. These rankings are shown in Figure 8, which makes it easy to compare the four alternatives. Each column represents one of the four prioritization schemes, with the highest priority enhancement according to that ranking system at the top of the column. Since the four schemes all prioritize higher over lower impact enhancements and lower over higher effort enhancements, there are some trends among the results. For instance, the highest priority enhancement according to all four schemes is adding certain new radiological agents, because it was rated a high impact, low effort enhancement. Likewise, the low impact, high effort task of conducting comparative analyses of alternate aerosol inhalation models was consistently rated the lowest priority enhancement across the schemes.

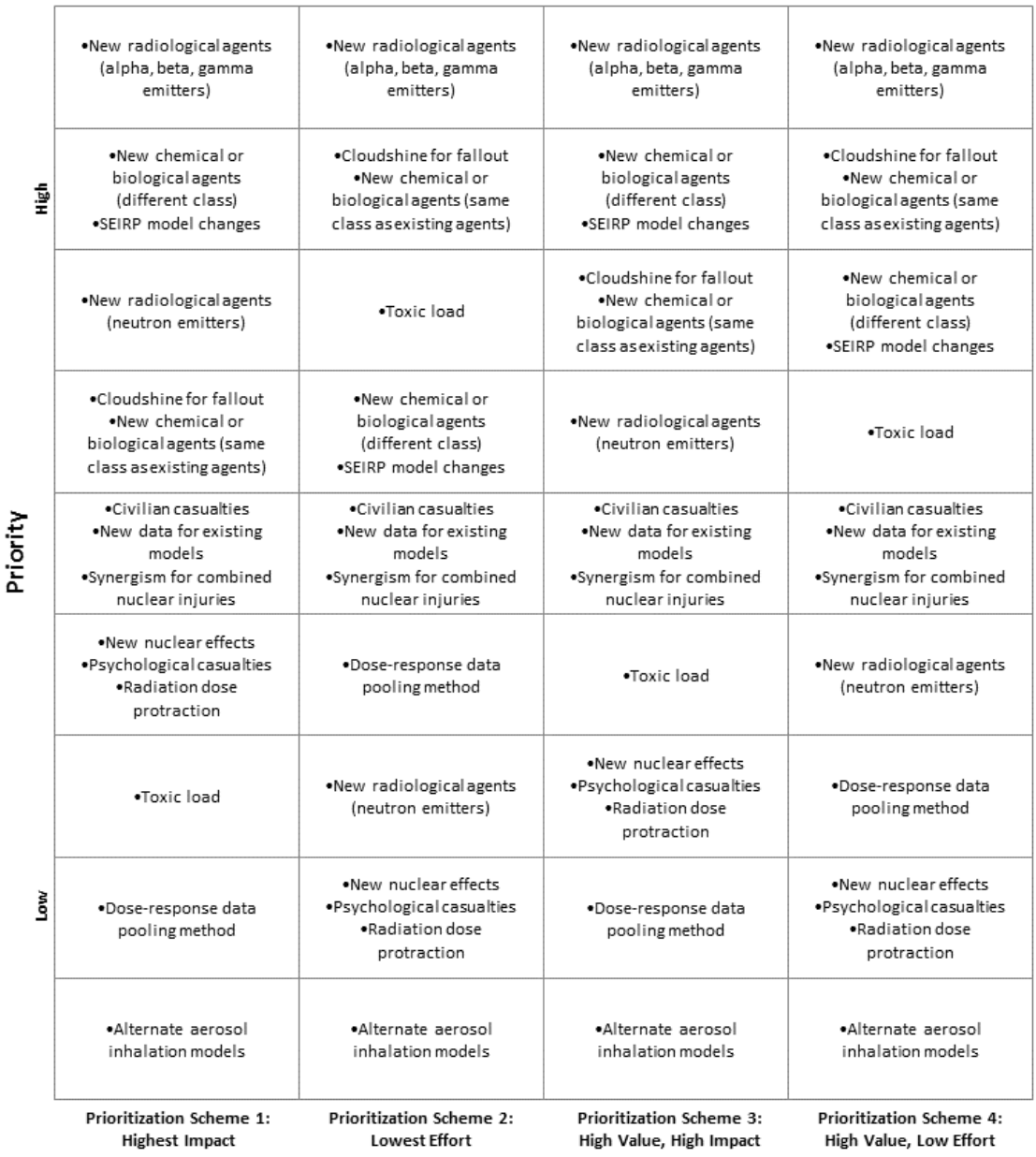

Figure 8. Prioritized Rankings of Potential Enhancements to the *AMedP-8(C)* Methodology Resulting from the Application of the Prioritization Schemes Shown in Figures 2 through 5

The specific order of the potential enhancements in Figure 8 is not as important as the framework for developing the prioritized lists. The process is qualitative, but transparent and easily adaptable. IDA (or the sponsors) could easily change these ratings if new information becomes available for any of the possible modifications described in Chapter 2 or if the sponsors disagree with the qualitative assessments of impact or level of effort. An added benefit of this framework is the ease of adding another potential enhancement to the prioritized list. When a new enhancement to the methodology is

identified, its impact and effort can simply be rated on the same three-point scale used for the enhancements described in this document to determine its placement on the matrix.

The IDA team recommends utilizing one of the four prioritization schemes to rank future enhancements to the *AMedP-8(C)* methodology: (1) Highest Impact, (2) Lowest Effort, (3) High Value, High Impact, or (4) High Value, Low Effort. However, the choice of which scheme to apply to the matrix depends on the sponsors' preferences and available resources. Using the prioritization schemes imposes deliberate consideration of the various alternatives for investing in future enhancements to the *AMedP-8(C)* methodology and helps inform the sponsors' decisions regarding how to allocate resources.

Appendix A
Illustrations

Figures

Tables

Appendix B
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Appendix C
Abbreviations

A	Activity
AFRRI	Armed Forces Radiobiology Research Institute
^{241}Am	Americium-241
^{241}Am/Be	Americium-241/Beryllium
AMedP-7.5(A)	*Allied Medical Publication 7.5 (A)*
AMedP-8	*Allied Medical Publication 8*
AMedP-8(C)	*Allied Medical Publication 8 (C)*
BZ	3-Quinuclidinyl Benzilate
CBRN	Chemical, Biological, Radiological, and Nuclear
^{252}Cf	Californium-252
^{60}Co	Cobalt-60
^{137}Cs	Cesium-137
CS	O-Chlorobenzylidene
CUD	Common User Database
D	Dangerous Activity Threshold
DOD	Department of Defense
EEE	Eastern Equine Encephalitis
GB	Sarin
GD	Soman
GLiPH	Group to Link Nonhuman Primate and Human Radiation Effects
HD	Distilled Mustard
^{131}I	Iodine-131
IAEA	International Atomic Energy Agency
IDA	Institute for Defense Analyses
^{192}Ir	Iridium-192
JRO	Joint Requirements Office
kg	Kilogram
^{99}Mo	Molybdenum-99
MOPP	Mission Oriented Protective Posture
MRV	Military Research Volunteer

NATO	North Atlantic Treaty Organization
OTSG	Office of the Surgeon General (U.S. Army)
PET	Positron Emission Tomography
^{238}Pu	Plutonium-238
^{239}Pu/Be	Plutonium-239/Beryllium
RDD	Radiological Dispersal Device
RM	Restriction of Movement
RTG	Radioisotope Thermoelectric Generator
SARS	Severe Acute Respiratory Syndrome
SEARCH	System for Evaluation and Archiving of Radiation Accidents Based on Case Histories
SEB	Staphylococcal Enterotoxin B
SEIRP	Susceptible, Exposed and Infected, Infectious, Removed, and Prophylaxis Efficacious
^{75}Se	Selenium-75
^{90}Sr	Strontium-90
^{170}Tm	Thulium-170
UK	United Kingdom
U.S.	United States
VEE	Venezuelan Equine Encephalitis
VX	Methylphosphonothioic Acid Nerve Agent
WEE	Western Equine Encephalitis
^{169}Yb	Ytterbium-169

REPORT DOCUMENTATION PAGE		Form Approved OMB No. 0704-0188

1. REPORT DATE (DD-MM-YY)	2. REPORT TYPE	3. DATES COVERED (From – To)
30 June 2014	Final	

4. TITLE AND SUBTITLE	5a. CONTRACT NO.
2013 Review on the Extension of the *AMedP-8(C)* Methodology to New Agents, Materials, and Conditions	DASW01-04-C-0003
	5b. GRANT NO.
	5c. PROGRAM ELEMENT NO(S).

6. AUTHOR(S)	5d. PROJECT NO.
Lucas A. LaViolet, Carl A. Curling, Project Leader	
	5e. TASK NO. CA-6-3079
	5f. WORK UNIT NO.

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)	8. PERFORMING ORGANIZATION REPORT NO.
Institute for Defense Analyses 4850 Mark Center Drive Alexandria, VA 22311-1882	IDA D-4802

9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR'S / MONITOR'S ACRONYM(S)
Office of the Surgeon General of The Army Health Care Operations (DASG-HCO-G34) 7700 Arlington Blvd, Ste 5143 Falls Church, VA 22042-5143	OTSG
	11. SPONSOR'S / MONITOR'S REPORT NO(S).

12. DISTRIBUTION / AVAILABILITY STATEMENT

Approved for public release; distribution is unlimited.

13. SUPPLEMENTARY NOTES

14. ABSTRACT

This is the fifth in a series of annual reviews on the extension of the casualty estimation methodology described in *Allied Medical Publication 8 (C): NATO Planning Guide for the Estimation of CBRN Casualties (AMedP-8(C))*. The objective of this document, the 2013 review, is to provide a framework to assess the relative costs and benefits of potential modifications to the *AMedP-8(C)* methodology to inform the prioritization of future efforts. The IDA team identified 14 potential enhancements to the methodology and heuristically assessed their implications, by ranking their impact and the level of effort required to implement them on an ordinal three point scale (high, medium, or low). The IDA team then described four schemes based on these ratings that could be used to prioritize the possible enhancements to the methodology and recommended that the sponsors select one of the four schemes based on their preferences and available resources.

15. SUBJECT TERMS

CBRN, AMedP-8, AMedP-7.5, Casualty Estimation, Human Response Model

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NO. OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT	b. ABSTRACT	c. THIS PAGE			MAJ H. Michael Stewart, Jr.
U	U	U	UU	56	19b. TELEPHONE NUMBER (Include Area Code) 703-681-8188